Canceling Spectrograph PSF Drift Error by Mixing Explain in Fourier space Interferometer Delay Pairs Modulation Transfer Function David Erskine (erskine1@llnl.gov) Horribly large and irregular PSF drifts Multiple delay EDI response Eric Linder (Lawrence Berkeley Nat. Lab.) afflicted native spectrograph Native spectrum vs time Feature Frequency, rho (cm) **EDI** = interferometer in series with your spectrograph EDI response **Benefits:** Desired res. 12000 Drifts of random polarity • 3x-10x+ **boost in resolution** across native spectrograph bandwidth, 20x - 350x+ boost in robustness against PSF drift, • (these stability benefits *multiply* your existing environmental control measures) Complete rejection of bad pixels, detector bias, other fixed pattern noises, · Defeat classical limits imposed by slit width, focal blur, wandering focal spot, sparse pixel density, irregularly manufactured pixel position, atmospheric distortions, But this does not spoil EDI hi res output spectra! thermal drifts, changing gravity vector, changing fiber mode shape, changing pupil Translational Reaction Coefficient shape, drifts in detector bias, Use of a spectral comb calibrator without spending \$\$\$, TRC = $\Delta\lambda$ Out / $\Delta\lambda$ Insult Precision Doppler radial velocimetry (exoplanet discovered in 2006, J. Ge group) Competitive overall photon SNR similar to native having classically reduced slitwidth Net Reaction Curve, Using original lineshape: 20x reduction Case: original lineshapes Photon noise uncorrelated with native so net SNR improved Local photon SNR at high feature frequencies vastly exceeds native EDI result is sum over wavelets. Native spectrograph Net reaction affects only envelope, not wavelet phase Cost: more complicated data analysis, some parasitic flux loss, read noise increase Resulting EDI shift ~0.025 cm-I fringing
nonfringing

Raw data shifted by 0.5 cm
nonfringing
Bnet4Qshifted TRC = 0.05Externally Dispersed Drift in Native spectrum 0.5 cm-I Interferometer Interferometer fixed delay = 1,2,3...5 cm Net Reaction Curve, Case: crossfaded lineshapes TRC=0 due to crossfading Grating spectrograph E1 E2 E3 E4 E5 **Absorption lines** Moire pattern 20x smaller reaction to native PSF wavelength shift Even smaller is expected with special weighting of lineshapes (under investigation) - Interferometer transmission Hale 200 inch telescope, Simulation using sinc function Reshape to Triangle or Cassegrain output, EDI lineshape and two delays Moire patterns produced by apparatus. Sinc function: 350x (black) sits atop (blue) What if moire patterns are shifted by $\Delta\lambda$ spectrograph error? NIR TripleSpec No worry, opposite moire slopes cancel! -(2700 res, 4100-11,000 cm-1, 2.4-0.9 micron) We describe demonstrations of remarkable robustness to instrumental noises by 8 using a multiple delay externally dispersed interferometer (EDI) [Fig2] on stellar observations at the Hale telescope [Fig1]. Previous observatory EDI demonstrations used a single delay. The EDI (also called TEDI) is an interferometer in series with a spectrograph, and has boosted the 2,700 resolution Output spectra from sum over of the native TripleSpec NIR spectrograph (950-2450 nm) by as much as 10x to wavelets, using multiple delays (d) Output spectra, after moire shifted 0.75 cm-1 to left 27,000, using 7 overlapping delays up to 3 cm. producing different wavelet periods Remarkably, we observed a ~20x reduction [Fig5, 7a] of reaction in the output spectrum to PSF shifts of the native spectrograph along the dispersion direction, using our standard processing. This allowed high resolution observations under (c) Reaction to conditions of severe and irregular PSF drift otherwise not possible without the interferometer. (e) Avg of 1.2 & 1.6 cm outputs Furthermore, we recently discovered an improved method of weighting [Fig8] and mixing data between pairs of delays that can theoretically further reduce the net reaction to PSF drift to zero [Fig7b]. We demonstrate a 350x reduction in reaction Method for implementing to a native PSF shift using a simple simulation [Fig9]. This technique could similarly reduce radial velocity noise for future EDI's that use two delays that are simultaneous multiple delays overlapping in delay space, or a single delay overlapped with the native peak. Output shift reduced 350x! We observed superb rejection of fixed pattern noises [Fig13] due to bad pixels, since the fringing signal responds only to changes in multiple exposures synchronous to the applied delay dithering. Native res element Method called We show an extremely high dynamic range EDI measurement [Fig13] of our ThAr lamp compared to a literature ThAr spectrum, observing weak features ~0.001x height of nearest strong line) that occur between the major lines. Because of "crossfading" individuality of each reference lamp, accurate knowledge of its spectrum between spectra, one for each the (unfortunately) sparse major lines is important for precision radial velocimetry. τ_{C} =0.9 cm etc Example EDI output spectra Comparing two stars Comparing our ThAr lamp to NIST lamp Extremely high dynamic range 6x res boost Both stars match telluric and ThAr lines 6x res boost Native spectra (thin: HD962, thick: HD219134) Telluric+ThAr model 2.4% of bright line @9548 Model, Kerber's FTS of ThAr, blurred to res 19000 4 0.008 NSO Solar, blue shifted 26.4 km/ NSO, Solar blue shifted 5.7 km/s EDI immune to bad pixels 12 Wavenumber (cm-1) SPIE proceedings Bad (but constant) pixel at X=1033, pollutes native spectrum but not EDI result Ar line heights: good agreement Little change between dashed and solid curves Telluric feature under two http://spectralfringe.org/ EDI/MyPubs4/ EdinburghSPIEgen.pdf different PSF drifts lamp much weaker (Dash & solid red curves) ≥ 0.004 These wiggles are not ringing, they are features! Jrnl artcl. on Data Anal & Instr. Noise Original http://spectralfringe.org/ (Solid red curve) TediTenxPart1gen.pdf 0.002 Bulk slant removed (Dashed red curve) Jrnl artcl. on Photon Noise Vavelets prior to summation: unaffected by shift. Underlying wavelets TediTenxPart2gen.pdf 9160 9260 9280 9180 9200 9220 9240 Wavenumber (cm-1) This work performed under the auspices of the U.S. Department of Energy by CASIS, May 18, 2016 Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. CASIS 2016 poster7.ezdraw 4/23/16